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A Comparison of Two Wide-Band Intercept Techniques

[UNCLASSIFIED]

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Countermeasures Branch
Radio Division

December 15, 1964
CNO Project D/S 341 FY 65
Radar Electronic Security Measures

U.S. NAVAL RESEARCH LABORATORY
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ABSTRACT

Two wide-open, multiple-band, crystal video intercept systems have been compared in an operational environment. The principal difference in the two systems was that one used the AN/SPS-8A radar antenna and the other the AS-570/SLR ECM antenna. Both used conventional crystal video receiving techniques and a novel radar PPI display consisting of concentric rings to represent the frequency bands and attached radial "spokes" to represent intercept bearing.

In addition, limited tests were made of (1) a proposed radar video tape recorder technique for display of radar information during intermittent radar operation, and (2) the usefulness of the intermittent radar technique to prevent detection by "snooper" aircraft.

It is concluded that radar antennas in general are inherently not suitable for wide band intercept applications. This is because of their narrow rf transmission band, restricted (normally linear) polarization, and low rotation speed. These characteristics are not compatible with acceptable intercept receiver performance.

On numerous occasions a true fleet EMCON condition, though prescribed, was not achieved or maintained. Violation occured from on board and nearby aircraft, and in a few cases from FORRESTAL's radars. This situation is serious in that a false sense of security may exist in the fleet commands. Any EMCON violation can also result in severe degradation in wide band intercept receiver performance. A partial solution exists by blanking and improved receiver techniques. However, it is recommended that fleet units initiate the necessary action to assure rigid compliance with EMCON conditions. An interesting corollary is that the wide open receivers provided an effective EMCON monitoring capability.

The use of intermittent radiation was of significant value in preventing detection by "snoopers". However, if radar contacts were weak or discontinuous, radar information was severely compromised by using intermittent radar radiation. If the contacts were illuminated consistently when radiating, the degradation in radar information was not significant. The limited tests have indicated that the diplay of recorded radar video during

radar "off" periods did not increase radar tracking ability as compared to intermittent radiation without redisplay.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem 54R06-10
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A COMPARISON OF TWO WIDE BAND INTERCEPT TECHNIQUES

INTRODUCTION

Project D/S 341 FY65 (Radar Electronic Security Measure) was established in accordance with references (a) and (b) in order to satisfy urgent requirements for a wide band, high intercept probability ECM receiver with improved display. Two experimental "quick-fix" receiving systems were installed in the USS FORRESTAL (CVA 59) and evaluated in a Mediterranean task force environment during the period 22 September to 4 October 1964. The purpose of these tests was (1) to evaluate and compare the early warning effectiveness of the two systems in covering the frequency spectrum from 2.3 Gcs to 10.75 Gcs, and (2) to determine the effectiveness of a video tape recorder technique for display of radar information during intermittent radar radiation. Since each intercept system utilized crystal video receiving and processing techniques and an AN/SPA-8A PPI concentric ring presentation to achieve coarse frequency resolution and bearing, the principal difference between the systems was that one employed an S-band radar antenna (AN/SPS-8A) and the other an ECM antenna (AS-570/SLR), both of which were already installed. The AN/SPS-8A receiving system was proposed and installed by a private contractor and the AS-570 system by NRL. Equipments remain on the FORRESTAL for further operational use and evaluation by the ship's force.

DESCRIPTION OF SYSTEMS

AN/SPS-8A Intercept System

The AN/SPS-8A system, Figure 1, utilized the radar antenna and feed system for either normal radar or ECM receiver operation. A SPDT waveguide switch, installed between the radar transmitter-receiver and the antenna, provided the desired mode of operation. When in ECM position, the antenna feed was switched into a tapered waveguide triplexer; each output in turn fed individual variable rf attenuators and low noise traveling-wave tube amplifiers. The triplexer was designed to separate the incoming signals into S-, C-, and X-bands. The TWT's were connected to crystal detectors and associated video amplifiers. The outputs of the video amplifiers then went to a three-channel display logic unit.

The logic unit performed signal storage and generated synthetic video signals for display. It was composed basically of three input storage flip-flops (one for each band) and a sequential readout. The readout was initiated by the SPS-8A prf trigger. The video output consisted of three relatively short pulses spaced so as to generate three concentric rings approximately 200 microseconds apart (approximately 2C radar miles) on the SPA-8 PPI. If no signals were present, only these rings appeared on the PPI.

When a signal pulse arrived, the event was stored by the appropriate storage flip-flop until the next readout occurred. This readout resulted in generation of a longer "signal" pulse which was applied to the PPI. The result was a widening or "spoke" occurring on the appropriate frequency band ring and at the bearing from which the signals arrived.

Sensitivity adjustments could be made only by manually varying the attenuation in the individual rf channels at the receiver location. However, broad band variable attenuators, suitable for remote control, were on order and the necessary control wiring was installed.

It is evident from the above discussion that this system utilized an S-band radar antenna and waveguide feed system to receive signals from S-through X-bands. Unfortunately, very little technical data was available on the efficiency of this transmission system at the time of the tests, except for co-polarized signals in the normal operating band of the radar.[1] At the time the project was assigned to NRL, a series of measurements was started on an SPS-8A antenna at the Chesapeake Bay Annex (CBA) concurrent with the operational tests. These measurements are now complete and will be reported separately.[2] Preliminary indications are that effective losses and variations in response of the order of 35 db may be expected even in

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1 One exception is in reference (c) which evaluated the SPS-8A antenna, in S-band only, as a potential wide band direction-finding receiving system. This report concluded that the radar is not suitable for such an application.

2 A report on the results in being prepared by Mr. N. J. Lesko of NRL. The title, report number, and date are not yet assigned.

the 2.0 to 3.0 Gc region of S-band. Also, these response patterns vary over comparable ranges as the rotary joints are turned due to rotation of the antenna. Figures 2, 3 and 4 show the response of the AN/SPS-8A antenna over the S- and X-bands as measured at CBA.

AS-570 Intercept System

The AS-570 crystal video receiving system, Figure 5, utilized the AS-570/SLR ECM antenna, which was used for the FORRESTAL AN/WLR-1 ECM receiver, to receive signals in S-, C- and X-bands. This antenna has two output waveguides to cover these three bands (crossing over at 5.5 Gc). These two feeds were connected to low noise TWT's. The outputs of the TWT's were fed to 3 db power dividers. One output of each power divider was connected to the WLR-1 and the other to a diplexer, which resulted in additional 10 db improvement in sensitivity on these bands on the WLR-1. The diplexers had crossovers at 4.0 Gc and 7.0 Gc. Thus, the incoming signals were sorted into four frequency bands: 2.3 to 4.0 Gc, 4.0 to 5.5 Gc, 5.5 to 7.0 Gc and 7.0 to 10.7 Gc. They were detected by four conventional crystal detectors and applied to separate video amplifiers and then to a four-channel display logic unit. Sensitivity measurements, waveguide insertion loss, and antenna performance data for the AS-570 receiver are shown in Figures 6, 7 and 8.[1] Antenna data was obtained from reference (d).

The logic circuit for this system is essentially the same as for the SPS-8A system except for two items: (1) there are four channels instead of three, and (2) the display readout is initiated within the logic circuit and triggers at approximately 3000 per second. This is about as high as the SPA-8 will trigger and sweep properly. The frequency band rings were spaced only about 25 microseconds due to the high prf.

The trigger and video (frequency band rings and signal pulses combined) were fed to the ECM control box which is attached to the SPA-8 PPI used for the ECM display. This control box contained relays which performed all the necessary switching when normal (radar) or ECM operation was selected.

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(1) The data in Figure 8 is taken from the AS-899( ) SLR antenna. This antenna is similar to the AS-570/SLR in performance.

To operate the SPA-8 as an ECM display, it was necessary to switch the ECM trigger, the ECM video and the ECM sweep resolver into the AN/SPA-8A. A separate sweep resolver was required because the normal AN/SPA-8A synchro system would not rotate at the high speeds at which the AS-570/SLR antenna normally operates (about 250 rpm). A high rotation speed is necessary for high intercept probability (see Appendix). For that reason, a separate synchro motor and sweep resolver, which were mounted in the ECM control box, rotated in synchronism with the AS-570/SLR antenna. The AN/SPA-8A deflection coil amplifiers were driven by this external resolver when operating as an ECM indicator. When in normal (radar) operation, the amplifiers are driven by the regular synchro-resolver system in the SPA-8 indicator.

A blanking system, Figure 9, was installed to reduce interference from the ship's own emitters. Blanking pulses were provided from the SPS-8A, SPS-10, SPS-12, SPN-6, SPN-12 and SRN-6 (TACAN).

Blanking was accomplished by feeding a pretrigger from each transmitter (via a cathode follower) to mixers which in turn triggered a two-channel blanking gate generator. This gate generator then generated a blanking gate for each input trigger which was used to blank the input channels of the display logic unit. These gates were about 20 microseconds long, adequate to overlap the transmitter pulses and nearby reflections.

Radar Video Tape Recorder

A video tape recording was used to provide continuous display during periods of intermittent radar radiation by connecting a seven-channel continuous loop recorder to a selected radar and displaying its output on a PPI. The recorder, which was placed in the Radar Switchboard Room, was connected to one of the regular radar positions on the switchboard. The recorder ran continuously, automatically updating (re-recording) radar information whenever the radar radiated.

Radar trigger, video and synchro (bearing) information were recorded during radiation periods. The frequency response of the recording system was essentially from DC to approximately 400 kc. A frequency modulated carrier technique was used for the low frequency portion of the video spectrum. Trigger, video, and synchro information playback channels were provided with suitable amplifiers to drive the SPA-8A PPI's.

DESCRIPTION OF TESTS

The tests were organized to evaluate the intercept systems and recorder techniques under a number of radar modes and parameters. These are outlined below.

Intercept Receiver Evaluations

Tests were conducted to determine and compare the maximum detection ranges, bearing accuracy and the effectiveness of the method of display as a function of: (1) radar frequency, (2) radar polarization (vertical, horizontal, circular), (3) radar mode (intermittent or continuous operation), (4) single or multiple radar targets, (5) aircraft altitude.

Frequency and polarization - Both aircraft and shipboard radars were utilized as target emitters in order to obtain as much variation of frequency and polarization as possible using the services available.

S-band - E1B aircraft - AN/APS-82, 2900-2950 Mc, horizontally polarized

USS SPRINGFIELD - AN/SPS-30, 3470 Mc, vertically polarized

C-band - USS SPRINGFIELD - AN/SPS-10, 5680 Mc, horizontally polarized

X-band - F4B aircraft - AN/APQ-72, 8776-9634 Mc, vertically and circularly polarized

A3B aircraft - AN/ASB series, 9375 Mc, horizontally polarized

USS SPRINGFIELD - Mk25-Mod3, vertically polarized

Radar Mode - Intermittent radiation ("winking") was arbitrarily specified to be two or three sweeps in two to three minute time intervals, as designated in each case. (Not all emitters could be switched instantaneously from "operate" to "standby" or conversely, as in the AN/APS-82, which required up to 15 seconds for the transition.) Continuous radiation, as the name implies, required continuous operation of the radar in its normal search mode, except in the case of the Mk-25-3 which scanned ±30 degrees of the FORRESTAL's bearing.

Single or multiple target emitters - Single target emitters closed the ship on radials from beyond the maximum range of detection to well within expected detection range at test altitudes. Multiple targets were used in two ways: (1) two or three aircraft closed on radials separated 40 to 50 degrees, (2) one or two aircraft were stationed in an orbit about 40 miles from the ship, with one aircraft closing on a radial from beyond maximum range of detection. The purpose of the multiple runs, in addition to the objectives set forth in the first paragraph of this section, was to compare the capability of the two systems in discriminating between (1) multiple targets of about the same signal strength that are radially separated, and (2) between strong signals and a weak emitter in the same band on about the same bearing.

Aircraft altitude - Both high and low altitude data were taken on each inbound run, with the aircraft commencing at high altitude and continuing at level flight until within the expected detection range, then descending to essentially "deck" level beyond the detection range at that altitude. Both outbond and inbound runs were utilized whenever aircraft radar antenna rotation would permit; in these cases, the inbound flight profile was flown in reverse on the outboard leg.

EMCON was prescribed, but not always achieved, for the FORRESTAL and non-participating aircraft in the bands under test and on other frequencies which were found to interfere with either of the two systems, and for other ships in the task force on all frequencies above 2000 Mc. (See comments relating to EMCON in the Test Results section.)

Operators and data takers were provided by the ship's force to report and record ECM contact information, which was later transcribed to a polar plot for correlation with the target's track, as reconstructed from combined search radar and aircraft TACAN/radar fixes. Video data fed to the AN/SPA-8A indicators from both intercept systems were recorded on tape for later analysis.

Tape Recorded Video Evaluation

The following techniques were tested and compared using a shipboard air search radar for long range air search and air control functions.

Intermittent operation of the radar - The radar operated during one or two azimuth sweeps in a predetermined time interval of silence. During the tests, this mode was simulated by switching the PPI video off during the silent intervals.

Intermittent radar operation with recorded video presentation - The video from one or two azimuth sweeps was recorded and redisplayed continuously during the interval in which the radar was silent.

Continuous emission.

In order to compare the presentations in the above, targets were tracked simultaneously on three PPI's using the foregoing techniques with radar inputs from either the AN/SPS-12 or AN/SPS-43A. The tests were constructed to (1) detect and track all targets of opportunity during routine air operations, and (2) to maintain track on designated multiple air targets simultaneously, in both cases recording bearings and ranges of each plot in order to determine the adequacy of track information and maximum range where applicable.

Air control intercepts were conducted for the purpose of determining the relative effectiveness of the three techniques.

As a corollary, the AN/SPS-12 air search radar was actually operated in an intermittent mode while snoopers made runs from beyond radar range in order to evaluate the effectiveness of the intermittent technique in avoiding detection. Snoopers reported maximum detection range and compared ease of signal analysis with data taken while the emitter was radiating continuously.

TEST RESULTS

Intercept Receiver

The tests were conducted under task force operating conditions in the Mediterranean with its attendant geographical and navigational restrictions, as well as difficult-to-enforce emission controls and operational scheduling problems. Despite the fact that these obstacles were largely overcome in matters under which control could be exercised, the tests were characterized by a high interference level in the bands under test from own ship, task force and aircraft, and from frequent interaction with non-cooperative aircraft and shipping in the crowded air and shipping lanes. Both systems were susceptible to interference from these unwanted signals and from side lobe energy which tended to mask or completely ring the scope. Erratic bearings and false target indications often resulted. For example, a single emitter such as a ship several miles distant, a nearby radio altimeter or aircraft radiating from the flight deck completely ringed a detection band on the PPI. This inability to discriminate a target from interference severely limited early warning capabilities and made the target designation task most difficult. Accordingly, test results were somewhat less valid than they would have been under fully controllable conditions, and certain subtle but important differences due to polarization and radar mode could not be determined. Range and bearing data, which are summarized in Table 1 are not indicative of maximum capabilities nor are they precisely repeatable. They are pertinent mainly for comparison purposes, since data was recorded for both systems in the same environment.

Based on the data and experience acquired during the test period, the AS-570 antenna system proved to be more effective in the S- and X-bands and the AN/SPS-8A system was better in the C-band, although the C-band tests were inconclusive since only one valid run was made. From the data it is seen that the maximum detection range of the two systems was approximately equivalent on S-band while varying each of the test parameters. However, bearing information from the AS-570 was less erratic and more believable, since good contacts were repeatable. The AN/SPS-8A appeared to receive strong target response in S-band, but it also received strong indications indications from "phantom" targets, side lobe energy that was non-repeatable and difficult to discriminate against, particularly with multiple emitters. From the limited tests at C-band, range and bearing performance of the SPS-8A was better than the AS-570, using the AN/SPS-10 as emitter (but see note regarding frequency criticality). At X-band, the AS-570 significantly outperformed the SPS-8A in both maximum range and bearing data. There were a number of entire X-band runs in which the SPS-8A system failed to detect the raid, and a few in which the AS-570 failed to respond. (It should be pointed out that very little frequency diversity within each band was possible due to the limited test vehicles available.)

Neither system demonstrated uniform frequency response over the entire spectrum. For example, the AS-570 was insensitive on the signal tested on C-band, when the radar frequency (AN/SPS-10) was near the diplexing system crossover frequency. In both C- and S-bands a nearby signal which was strong on the AS-570 was weak on the AN/SPS-8A despite the appearance of other strong signals on the AN/SPS-8A, indicating "holes" in the response of the latter. Further, performance of the AN/SPS-8A in X-band indicates poor overall frequency response.

Inconsistencies were observed in the range and bearing data obtained between runs of similar type and between dissimilar runs which were designed to show differences due to altitude, polarization, and mode of operation. These inconsistencies are attributed to false targets caused by interference, bona fide targets masked by interference, variation in emitter frequency and power output, and relative effectiveness of emitter scanning. Effects of cross-polarization and emitter mode of operation were therefore inconclusive because of these conditions which could not be controlled. Inasmuch as the problem is essentially statistical in nature, a large volume of data under absolutely controlled conditions would be required to average out these inconsistencies. These requirements were beyond the scope of this evaluation and impossible under the environment which prevailed.

SECRET

TABLE 1
RANGE AND BEARING SUMMARY INTERCEPT RECEIVER

Freq. Band-Polarization	Run Type	Mode	No. of Runs[2] AN/SPS-8A	No. of Runs[2] AS-570	Ave max detection range,[1] mi/Ave bearing deviation[3] AN/SPS-8A	Ave max detection range,[1] mi/Ave bearing deviation[3] AS-570
S-horiz.[4]	1 plane,	Contin.	3	3	160/±9°	161/±7°
	12,000'	Intermit.	1	1	102/±7°	162/±3°
S-horiz.	1 plane,	Contin.	6	6	50/±3°	53/±3°
	100-500'	Intermit.	2	2	57/±4°	64/±2°
S-horiz.	2 planes, 3500'	Contin.	1	1	100/±5°	96/±2°
S-horiz.	1 plane,	Contin.	1	1	152/±9°	160/±3°
	3500' (1 orbit)	Intermit.	1	1	100/±4°	82/±4°
S-vert.	Ship	Contin.	1	0	44/±4°	--
		Intermit.	1	0	36-1/2/±1°	--
C-horiz.[5]	Ship	Contin.	1	1	44/±5°	44/±8°
X-circular[6]	1 plane,	Contin.	3	4	0	183/±4°
	35,000'	Intermit.	1	1	252/±9°	126/0°
	1 plane,	Contin.	2	5	9	67/±2°
	100-500'	Intermit.	1	1	25/±3°	35/±1°
X-vert.	1 plane,	Contin.	3	3	87/±4°	219/±2°
	35,000'	Intermit.	2	2	105/±9°	108/±1°
	1 plane,	Contin.	3	3	8/±20°	55/±3°
	100-500'	Intermit.	2	2	33/±2°	46/±1°
	3 planes,	Contin.	3	3	79/±5°	89/±2°
	4000'	Intermit.	3	3	11/±3°	39/±3°
(2 planes	1 plane,	Contin.	3	3	71/±3°	92/±3°
orbiting)	4000'	Intermit.	2	2	34/±8°	103/±3°
	Ship	Contin.	1	1	32/±2°	40/±2°
		Intermit.	1	1	30	33.5/±1°

SECRET

NOTES FOR TABLE 1

1. The average maximum detection range is defined to be the average of the maximum ranges at which a valid contact was believed to exist.

2. Although data was generally taken on each run on both systems, there were a few cases in which interference levels prevented data collection on one system or the other. Hence, a different number of runs is listed for the two systems in the data summary.

3. Bearing deviation is used instead of bearing accuracy because of correctable constant errors presumably caused by system misalignment or inaccuracies in reconstruction of target tracks. Hence, bearing consistency is a more valid comparison.

4. On S-band, in general, the AS-570 System presented fairly consistent bearing information with smaller deviations than the AN/SPS-8A, which gave erratic bearings, particularly with multiple targets or interference present.

5. The C-band test signal appeared weak and erratic on the AS-570; the signal was strong and bearings fairly consistent on the AN/SPS-8A antenna.

6. On X-band signal, the AS-570 System bearings were consistent with small deviations, whereas the presentation on the AN/SPS-8A was weak and erratic.

Tape Recorded Video

Because of time limitations and the desire to make maximum use of available services in evaluating the intercept receivers, data on this phase is insufficient to evaluate conclusively the intermittent video concepts, although data taken is pertinent and accordingly reported herein. Data summary is included as Table 2.

Using the AN/SPS-12, which provided marginal radar performance at best, with either the intermittent or recorded video technique, the early warning and target tracking capabilities were degraded to such an extent that while four and five bogey tracks were being maintained by the "continuous" plotter, only one or two simultaneous targets were detected or plotted using either intermittent technique.

In tracking four targets with consistent information from the AN/SPS-43A radar, the intermittent and recorded video presentations were equivalent in performance and both provided good tracks.

With good radar information, the air controller was able to make a successful, timely intercept using the intermittent technique. Experienced air controllers were reluctant to try either intermittent or recorded video concept with AN/SPS-12 radar because of the paucity of signals. Air controllers considered that a delayed, recorded presentation would be confusing in dead reckoning and that the absence of IFF would prevent rapid detection, identification and plotting of friendlies during an intercept.

Effectiveness of the intermittent radiation technique in reducing the probability of intercept by snoopers was demonstrated on seven runs in which snoopers, which were APR-9 equipped, intercepted the wrong signal, which was similar to the target, and never properly identified the FORRESTAL's AN/SPS-12. In two actual intercepts by snoopers, analysis and df were made much more difficult and occurred at a closer range from the ship than normally experienced.

For small targets, the quality of the recorded video appeared to be essentially equivalent to direct radar video, as viewed on the SPA-8A. However, a range difference of about one mile was noted between radar and recorded video presentations. This discrepancy was independent of PPI range setting. In addition, there was an observable difference in the appearance of large targets, such as land masses. The recorded video display tended to emphasize the near (leading) edge of such a target, indicating a probable deficiency in low frequency response.

The tape recorder was not synchronized with the radar antenna, which resulted in a rapid swing of the azimuth strobe when switching the PPI to the recorder from another radar presentation. A flyback and overlap occurred on each rotation of the sweep when operating the indicator from the recorder, depending on how closely the tape loop was adjusted to a complete 360 degree rotation of the antenna.

TABLE 2 - TAPE RECORDED VIDEO DATA SUMMARY

1. Tracking

a. Multiple tracks (designated)

Radar AN/SPS-43A, Range to 210 miles, Time 1 hour

Mode	No. of Targets	Adequacy of Track
Intermittent Video	4	About 90% complete (1 plot missed in each track)
Recorded Video	4	About 90% complete (1 plot missed in each track)
Continuous Operation	4	Nearly complete track information

TABLE 2 - TAPE RECORDED VIDEO DATA SUMMARY (Cont'd)

b. Multiple tracks (all targets of opportunity)

Radar AN/SPS-12, Range to 114 miles, time 4 hours

Mode	No. of Targets	Adequacy of Track
Intermittent Video	1-2	Poor, incomplete, little continuity
Recorded Video	1-2	Poor, incomplete, little continuity
Continuous Operation	4-5	Fair continuity

2. Air Control

Data incomplete.

One intercept was successfully conducted using the intermittent technique with AN/SPS-43A radar information. None attempted with recorded video due to time limitations.

Due to paucity of AN/SPS-12 radar information and lack of IFF with recorded video, neither intermittent nor recorded video techniques were used with this radar.

3. Intermittent Operation

Ship radar - AN/SPS-12

Intermittent radiation - normally 12 sec (2 sweeps) in 3 to 4 minutes

Snoopers - EA1F aircraft with APR-9 intercept equipment

Mode	No. Runs	No. Runs Signal Detected	Ranges at Detection	Range when analyzed
Intermit.	9	2	75, 50	60, -
Contin.	2	2	70, 58	68, 52

REMARKS on Table 2

1. On seven intermittent radiation runs, snoopers intercepted the wrong signal in the band and did not detect the FORRESTAL radar.

2. Detection of continuous radiation was made almost immediately after inbound run began. Detection of intermittent radiation occurred 8 and 15 minutes after turn-around, and signal analysis was accomplished with difficulty.

CONCLUSIONS

At first glance, it might appear that a radar antenna would be an excellent choice for intercept applications because of a large effective capture area. However, it has been shown that, in effect, this large aperture exists only for specific signals. In general, it can be said that radar antennas are optimized to gather radar, not intercept, information and that the parameters for the two problems are widely divergent.

The measured performance of the SPS-8A antenna (see Figures 2, 3, and 4) clearly indicates that very poor performance would be expected, in an intercept application, for signals outside the 3.0 to 4.0 Gc region and even for cross polarized signals in that region. Effective antenna gain variations of 35db or so were measured.[1]

The usefulness of radar antennas for intercept purposes is also severely compromised by their low rotation rates (see appendix). This is particularly true if the emitter is in a "winking" mode.[2]

1 This corresponds to a free space detection range ratio of about 60 to 1. For example, two emitters of equal beam power, but on slightly different frequencies might have expected line of sight detection ranges of 600 miles and 10 miles.

2 A "Winking" mode is specified in the Soviet AS-1 (Komet) radar operators handbook.

The net result is that a radar antenna will not provide a uniformly sensitive, high probability-of-intercept, receiver capability.

For the above reasons it is concluded that present day radar antennas are a poor choice for intercept receiver applications. Suitable antennas, optimized for intercept df use, are already available. The AS-570 and AS-899 are examples.

As previously mentioned, even though EMCON was prescribed, emitters were often energized during the test periods. In some instances these were never specifically identified. In others they were analyzed by the WLR-1 operator and identified as true EMCON violations from such sources as aircraft on the flight deck, radar altimeters in helicopters, and nearby aircraft. Even FORRESTALS's radars, in a few instances, activated in violation of EMCON.

It is therefore concluded that rigid EMCON was not achieved by the task force. This has serious implications for both tactical and technical reasons. First, a false sense of security will exist in the fleet Commands. In addition, the capabilities of a wide band intercept receiver cannot be fully realized in the presence of this interference. One or two strong interfering signals can make one band of such a receiver virtually useless. Some relief can be obtained by receiver improvements (see recommendations), but such a wide open receiver is still fundamentally very susceptible to interference.

The AS-570 system proved to be more effective as a wide band intercept system that the AN/SPS-8A. The high data rate (rapid antenna rotation) provided an advantage in detection probability and in bearing repeatability; its wide band response provided an advantage in covering the overall spectrum, particularly in the X-band.

Both intercept systems demonstrated limitations and require further engineering before being considered acceptable as an interim wide band intercept system.

Under rigid EMCON conditions, and in the absence of strong interfering radiation, either system will provide a limited instantaneous intercept and signal identification capability when used in conjunction with the WLR-1. However, the effectiveness of both systems can be rapidly and seriously degraded by one or two interfering radiations, either from own ship or noncooperative ships and aircraft in the vicinity.

Blanking from the ship's own emitter is essential, since there are numerous situations when use of local radars may be required (such as flight operations) and continuous use of the intercept system is desirable.

There was evidence of "holes" in the frequency responses of both systems.

The display of simple single threshold digital signal information without amplitude indication is very ineffective in signal discrimination and deficient from a human engineering point of view in providing an easy-to-read presentation.

The PPI display of wide-band ECM information in CIC is a significant step forward, although possibly not the ultimate answer, to rapid dissemination of ECM information to ship control for early warning purposes.

Both systems can function as effective EMCON monitors to enable the force commander to determine whether silence conditions are being enforced. With close coordination between the AN/WLR-1 and the wide band systems, offending signals can be ferreted out.

The intermittent radar-recorded video tests, though limited, have indicated that:: (1) Intermittent radiation can very significantly reduce the probability that any particular radar will be detected by a snooper aircraft. (2) If radar information is not of high quality, radar detection and tracking ability can be seriously reduced by using intermittent radiation. (3) For a modest number of tracks, the use of recorded video was of no apparent advantage in acquisition, maintaining track, or in air controlling, as compared with the use of unaided PPI with intermittent information.

More comprehensive analysis and testing of these techniques are required before firm conclusions may be drawn. Considerably more data and operational experience must be obtained to determine the value of the intermittent radiation technique.

The video tape recorder can reproduce radar video essentially equal in quality to the original. The previously mentioned range discrepancy and apparent low frequency limitation are probably correctable.

The flyback problem is a more difficult one. It may be solved by synchronizing the recorder to the radar antenna, by tailoring the tape loop to a specific antenna rotation rate and restricting the radar to that antenna rate, or by manual readjustment of the tape loop whenever antenna rotation rate or radar is changed.

The readjustment of tape loop, need for daily replacement or resplicing of tape, and replacement of recorder heads (at about $1500 each) after approximately 1000 hours of service constitute a maintenance and logistic disadvantage to the system.

RECOMMENDATIONS

As previously discussed, tests data collection and interpretation were complicated by interfering emissions, and it is probable that a few of these were recorded as valid contacts, and that some valid contacts were not allowed, resulting in a loss of valuable data. Accordingly, it is recommended, if further evaluation of the present intercept systems is deemed necessary, that it be performed in a rigidly controlled environment. Such a test might be conducted by COMOPTEVFOR, for example, using a single vessel, located out of shipping and air lanes.

It is recommended that radar antennas not be used for passive intercept purposes. Even in the relatively narrow frequency bands where they are efficient transmission systems they are compromised by restricted (linear) polarization, and low rotation speeds. The result is an extremely low probability of intercept, particularly for "winking" radars, which use a known Soviet technique. A wide band passive intercept system should be capable of high rotation rates, responsive to all normal signal polarizations, and exhibit essentially uniform response to the entire frequency spectrum. Radar antennas do not meet these requirements.

It is recommended that fleet commanders review EMCON effectiveness in their various units and implement the necessary controls and safeguards to assure rigid compliance. The facts are that violations did occur during the tests. These violations were primarily from aircraft, both on board and airborne. Typical sources were on board aircraft radar during maintenance and check out, pre-launch energizing of radar, plane guard helicopter radar altimeter, and on station tanker aircraft. On a few occasions EMCON violation occurred from the FORRESTAL's own radars.

In some cases it may be necessary to consider the impact of complete EMCON on Task force mission effectiveness. In other words, some of the above EMCON violations may contribute directly to the successful completion of the mission.[1] When EMCON is prescribed, procedures should be established which minimize the impact on the effectiveness of the carrier and its elements.

In considering a recommended course of action to satisfy the urgent need for a wide band passive intercept system, the inherent susceptibility of a wide band receiver to interference should be reemphasized. Usefulness of the wide band receiver concept is therefore limited to a low signal density, essentially the situation where friendly emissions are rigidly controlled. This vulnerability to interference can be reduced somewhat by improved receiver techniques, video processing and antenna design, but the present state-of-the art is a limiting factor. With these basic limitations in mind, a development program is recommended which can provide an improvement over the FORRESTAL installation in the near future, with updating as permitted by technical advances and which would provide a capability in a low density signal environment.

1 For example, it is understood that the A4 navigation system is routinely energized (requiring radiation) prior to launch for better navigation accuracy.

Short range development (estimated one year) - Two alternatives are proposed, one utilizing existing AN/SPA-8A indicators with quantized processed video, and the second utilizing a development multi-gun indicator which would simultaneously display analog video from each channel. Either system is predicated on making maximum use of existing (presently installed or in-production) ECM equipments with a minimum development effort required to alleviate the most serious deficiencies described in this report. The short time frame is predicated on assignments of a high priority, maximum effort program.

The system utilizing AN/SPA-8A PPI's is similar to the AS-570 system installed on the FORRESTAL with the following improvements:

(1) Signal processing which will provide quantized amplitude indication and interference rejection.

(2) Improved blanking utilizing the AN/SLA-10 to reduce interference from own ship's radars.

(3) Optional use of several PPI's simultaneously.

(4) Separate antenna control unit for lower frequency df antennas (AS-616 and AS-571) on the WLR-1.

(5) Display of K-band information from the AN/SLR-12.

(6) Audible signal readout.

(7) Separate, compact PPI for full time use of ECM operator and for installation in CIC under conditions where a radar PPI is not available.

(8) Use of new generation in-production equipments, such as AS-899 antenna, AN/WLA-3 amplifier, four-channel video amplifier, AN/SLR-12 and existing AN/SPA-8A PPI's.

(9) Adaptable to NTDS, and thus compatible with SINEWS I or II.

Items (1), (2), (8) and (9) are essential to the basic system; the remainder are relatively inexpensive improvements which are highly desirable to increase the system effectiveness and flexibility.

To accomplish these objectives, development is required of the signal processing unit, which is the controlling factor in the development phase. Additional engineering development will be required for the control and distribution hardware (resolvers, electronic switch, sweep generator and distribution unit), audible signal readout circuitry and a compact PPI indicator for ECM operator or further application in CIC. It is expected that these ancillary devices can be completed within the development cycle of appropriate signal processing equipment.

Estimated costs of the system shown in Figure 10 are as follows:

Items	Development	Production	Installation
Logic/Control	$60,000	20,000	3,000
Mods to AN/SPA-8A	7,000	1,000 indicator	1,000/indicator
Indicator	25,000	2,000	1,000
C-1609/AM1017	---	5,000	2,000
SUB TOTALS	$92,000	30,000/3 indicators	9,000/3 indicators

The analog video system would be similar to the preceding except for the following items, which refer to the correspondingly numbered subparagraphs:

(1) Analog video, instead of processed digitized video, would be provided to five-gun PPI displays, thus giving amplitude discrimination directly without conversion to digital form.

(7), (8) The multi-gun diplays would be used whenever required, instead of other separate PPI's. AN/SPA-8A's would not be required.

Engineering development would be required for the five-gun PPI, the resolver system, distribution amplifier, and audible signal readout circuitry. This system could also be realized in about a year.

Estimated costs of the system shown in Figure 11 are as follows:

Item	Development	Production	Installation
Indicator	$25,000	2,000/indicator	1,000/indicator
C-1607/AM1017	---	5,000	2,000
Resolver/Indicator	50,000	15,000	3,000
SUB TOTALS	$75,000	28,000/4 indicators	9,000/4 indicators

Relative advantages and disadvantages of the two alternatives are as follows:

RADAR PPI (AN/SPA-8A)

Advantages - PPI's already are installed; ECM information readily available to CICWO and ship control; ECM presentation may be alternated with radar presentation on scope for correlation.

Disadvantages - Some loss of sensitivity due to processing technique; PPI's must be modified to permit high speed sweep rotation, and different PPI types may require different modification; more complex system; PPI's not available for intercept purposes on full time basis.

ANALOG VIDEO SYSTEM (Multi-Gun Indicator)

Advantages - ~~Better~~ signal discrimination; PPI's available full time to CIC watch; system is less complex; system design may be independent of non-ECM equipments; slightly better sensitivity anticipated.

Disadvantages - Additional equipments with corresponding space requirements.

It is considered that a better system will result using the Analog Video System. Accordingly, this approach is recommended.

Longer range development (estimated one to three years) -

(1) Parallel development of side lobe reduction (or cancellation) technique for use with the AS-899 and AS-899 antenna improvement or replacement.

(2) Signal identification capability.

(3) Advanced signal processing techniques (e.g., tunable notch filter, prf and pulse width discrimination, CFAR, etc.).

(4) Advanced receiver design, such as the EWIR or SAIS receivers now under development.

Estimated research costs are $150,000 per year FY1965 to 1968.

Project SHIELD (1970's) - Project SHIELD should reflect the requirement for a highly sensitive, high data rate, wide band intercept system capable of operating in a moderate signal environment and should provide direction for its development. The recommendations in Short Range Development and Longer Range Development should be applicable and provide inputs useful to the long term developments in SHIELD.

It is recommended that tests and analysis of the recorded video concept be continued by the FORRESTAL in order to determine conclusively the need for and effectiveness of the recorded video concept. If it is demonstrated that recorded video is an operational necessity, consideration should be given to a more nearly optimum approach, since there are inherent disadvantages to the tape recorder technique. Besides the maintenance and adjustment problems previously discussed, the high initial cost ($25 to 30 K) and cost of upkeep ($1.5 K for heads) are not consistent with maximum cost effectiveness principles. Other storage techniques should thus be compared on the basis of cost, performance and maintainability.

REFERENCES

(a) Naval Message, Ch Nav Mat 2614292 (Aug, 1964)

(b) Naval Message, CNO 1114352 (Sep, 1964)

(c) NRL Memorandum Report 1137; "Evaluation of the AN-484A/SPS-8A Radar antenna over an Extended Frequency Range (Unclassified Title)", R. L. Eilbert, Jan, 1961

(d) AS-899 ( ) Preproduction Inspection Report. Prepared for BuShips under contract NObsr-89535

ACKNOWLEDGEMENTS

Commander J. T. Geary and Mr. W. Steed of the Bureau of Ships participated in conduct of the tests, reduction of the data and in the preparation of this report. Their efforts are gratefully acknowledged.

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Mr. Norman J. Lesko of NRL provided measured data on the AN/SPS-8 radar antenna and feed system.

APPENDIX

THE INFLUENCE OF INTERCEPT ANTENNA ROTATION RATE ON PROBABILITY OF INTERCEPT

One of the important factors in determining the probability of intercept of a receiver using a rotating antenna for direction of arrival determination (df) is the rate at which the receiving antenna rotates. If "winking" radar techniques are used, this factor assumes a primary role in determining the time to intercept.

Since the rotating antenna df technique requires relatively narrow beamwidths for a reasonable bearing accuracy, and since the radar antenna beamwidth will also be narrow, the probability of df main lobe-to-radar mainlobe detection will be small. Therefore, the df problem is essentially one of detecting the radar side lobes.

For effective radar side lobe detection the intercept receiver sensitivity must be some 30 to 40 db (the radar main lobe to side lobe ratio) greater than that required for radar main lobe detection. Since the intercept antenna main lobe to side lobe ratio will not be better than this, false df intercepts will occur when the radar main lobe illuminates the intercept receiver side lobes. Similar effects will occur from all radars within detection range.

Since these false df indications will occur even in an ideal environment, and since they will increase directly with signal and interference density, some technique must be used to recognize the valid contacts.

In general, the false contacts will not appear at the same bearing on successive intercept antenna rotations. Thus, if a few successive rotations indicate a constant bearing contact, it will generally be valid. The point to be made is that a single contact on a single intercept antenna rotation cannot be considered a valid df intercept, and that an absolute minimum of two would be required. If the radar was radiating continuously, the time required for a 50% probability of n successive intercepts is simply

$$t = \frac{(a - 0.5)60}{r} \text{ seconds} \tag{1}$$

where t = time for 50% probability of intercept
a = number of successive contacts required
r = intercept antenna rpm

This is plotted for two, four and six successive intercepts on Figure 12. This clearly indicates the advantage of using a high intercept antenna rotation rate. For example, if the intercept antenna rotates at 10 rpm, it requires a minimum of 9 seconds to obtain a 50% chance of two successive intercepts. At 100 rpm, less than one second is required.

When the radar is "winking", the high intercept antenna rotation rate is even more advantageous. For example, if an APQ-72 radar operator was illuminating the target for 3 sweeps (approximately 3 seconds), an intercept antenna would have to be rotating at 30 rpm to have a 50% probability of two successive intercepts and at 20 rpm, there is no possibility of two successive intercepts. At 110 rpm, there is a 50% probability that six successive intercepts will be made.

The time to intercept for a "winking" radar can be computed by considering the probability that two successive contacts will occur in a single radiation period.

$$p = \frac{t_r - t_i}{t_r} \; ; \; (t_i < t_r < 2t_i) \qquad (2)$$

Where p = the probability of two successive contacts
t_i = time for one revolution of intercept antenna
t_r = time emitter radiates

The number of chances (radiation cycles) required for a specified probability that two successive intercepts will have occurred is

$$1 - (1 - p)^n = P \qquad (3)$$

or

$$n = \frac{\log (1 - P)}{\log (1 - p)} \qquad (4)$$

where

n = number of radiation cycles

P = probability that a radiation cycle has resulted in two successive contacts

This expression will give the average time to intercept, for a specified emitter on-off period, if P is set at 0.5.

$$T = \frac{D}{2} + D\frac{\log(0.5)}{\log(1-p)} \qquad (5)$$

where D is one total on-off period of the emitters, and T is the average time to intercept. It should be noted that expression (5) is strictly true only if the emitter off time is large compared to the on time. The D/2 term is present because there will be an average wait of one-half of an emitter period before radiation begins.

Expression (5) is plotted on Figure 13 for a radar total on-off cycle of 3 minutes and radiation periods of 6, 3 and 1.5 seconds.

The advantage of high intercept antenna rotation rate is apparent. For example, at 11 rpm and 6 seconds emitter on time, the average time to intercept would be about 12 minutes. At 10 rpm there is no chance for intercept. At 60 rpm the average time to intercept is the minimum (1.5 minutes) even with 1.5 seconds radiation time.

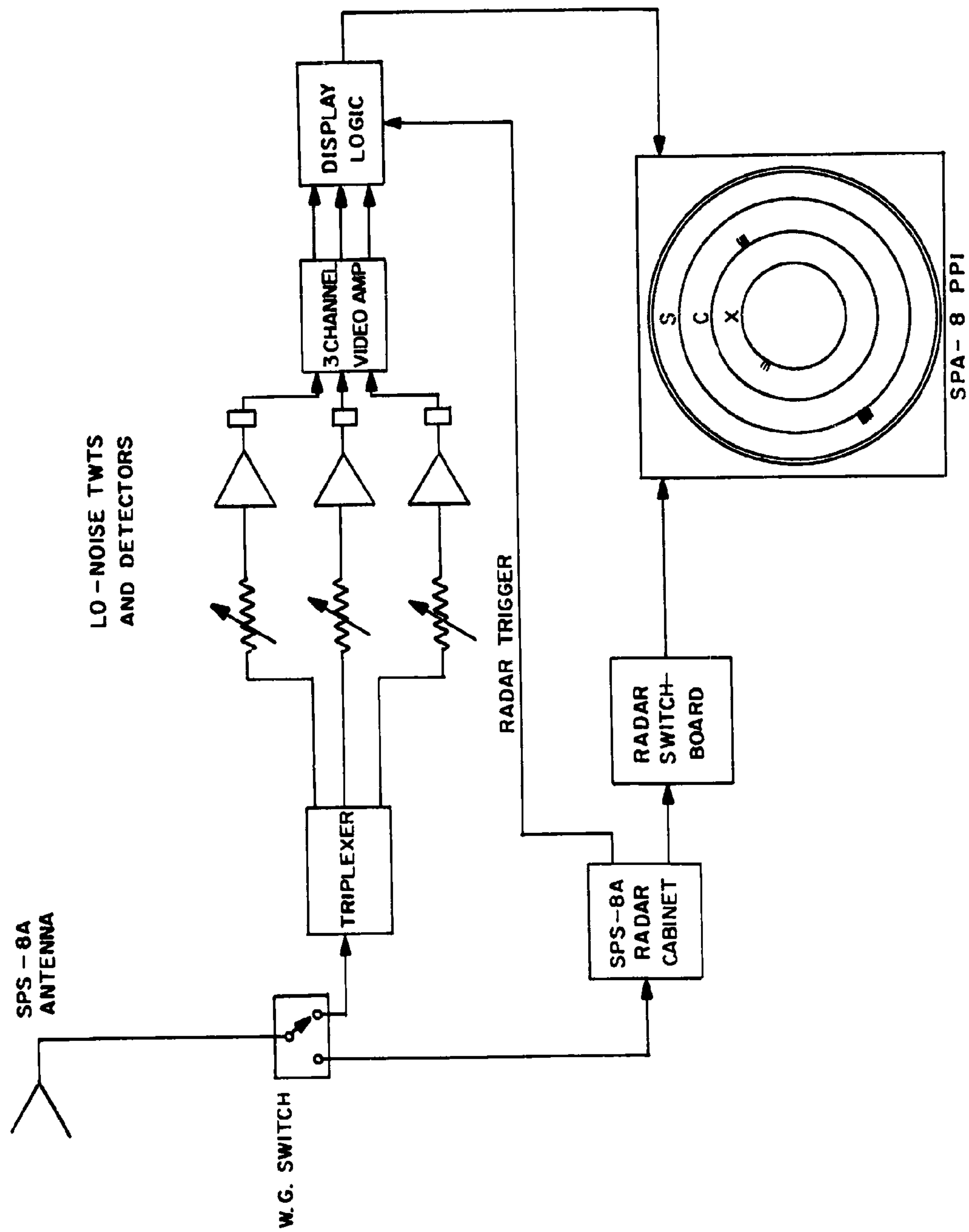

Figure 1 - AN/SPS-8A Intercept Receiver

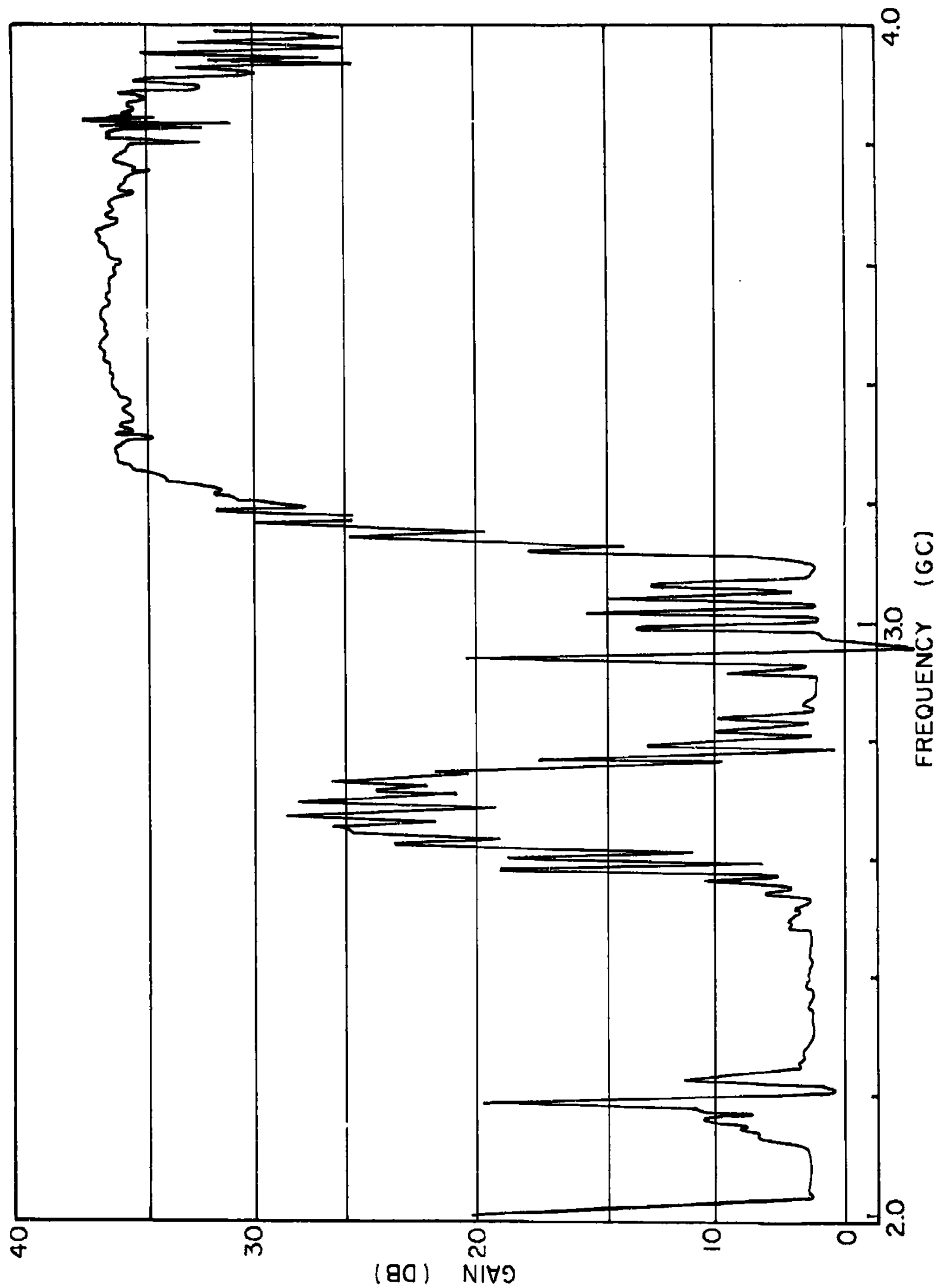

Figure 2 - S-Band Co-Polarized Effective Antenna Gain of AN/SPS-8A

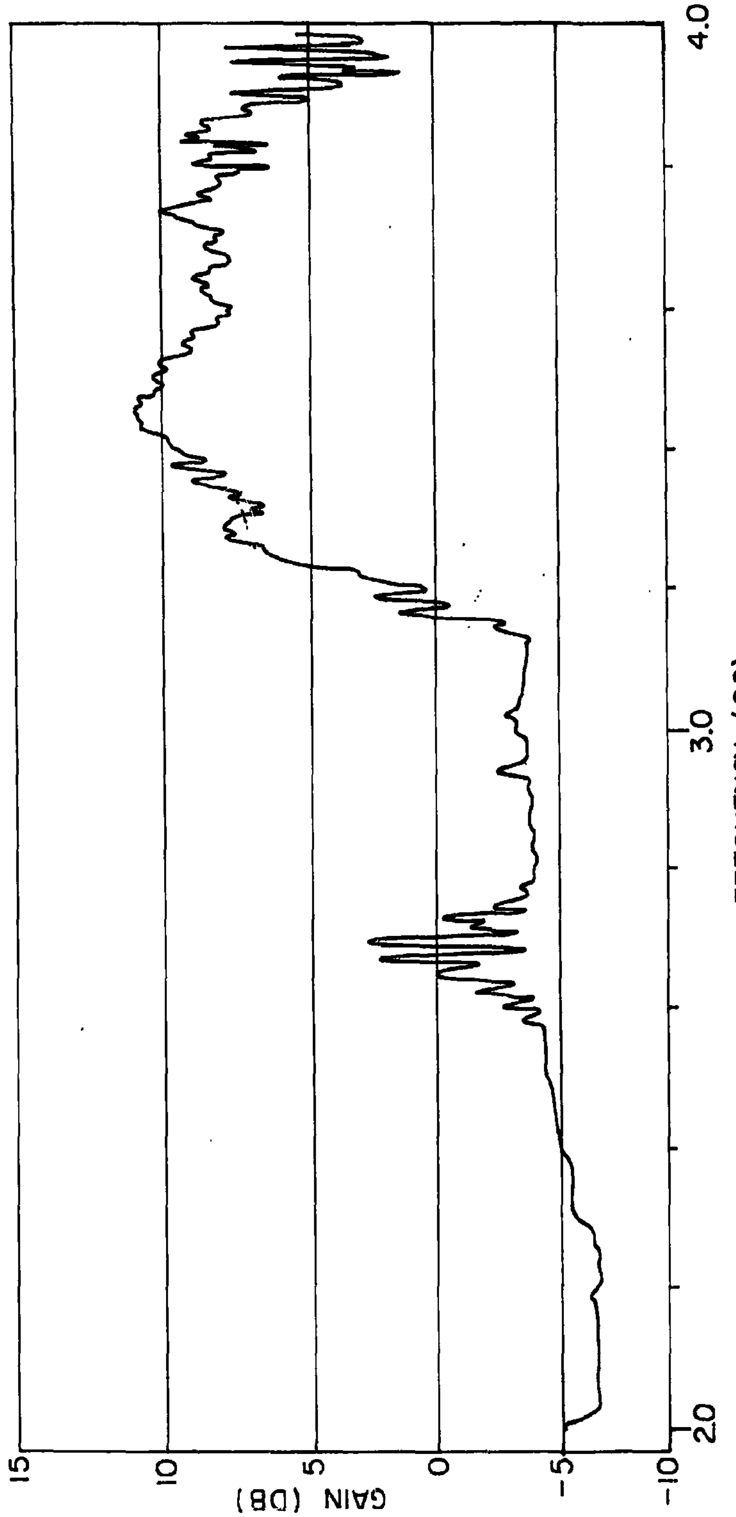

Figure 3 - S-Band Cross-Polarized Effective Antenna Gain of AN/SPS-8A

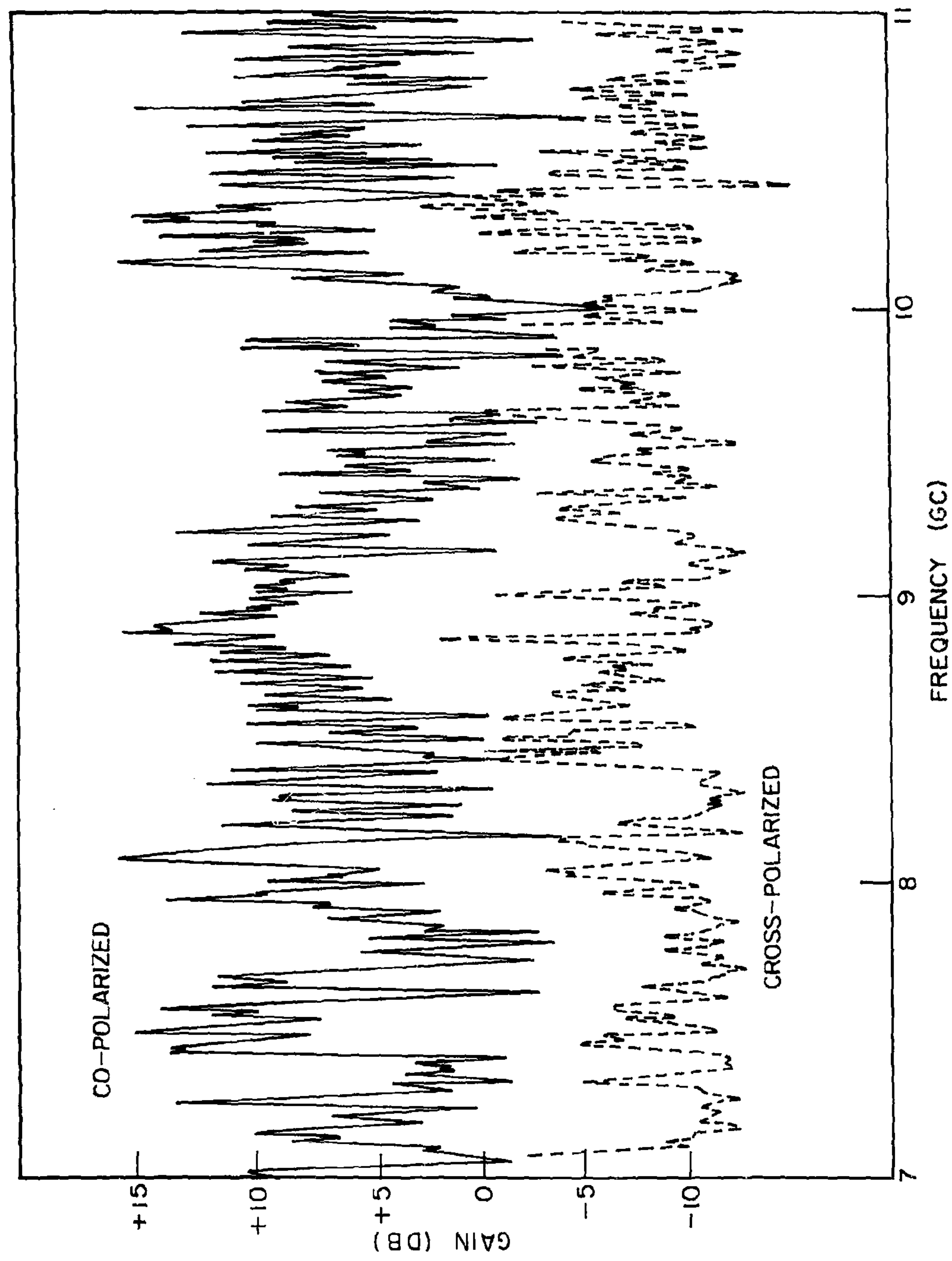

Figure 4 - X-Band Effective Antenna Gain of AN/SPS-8A

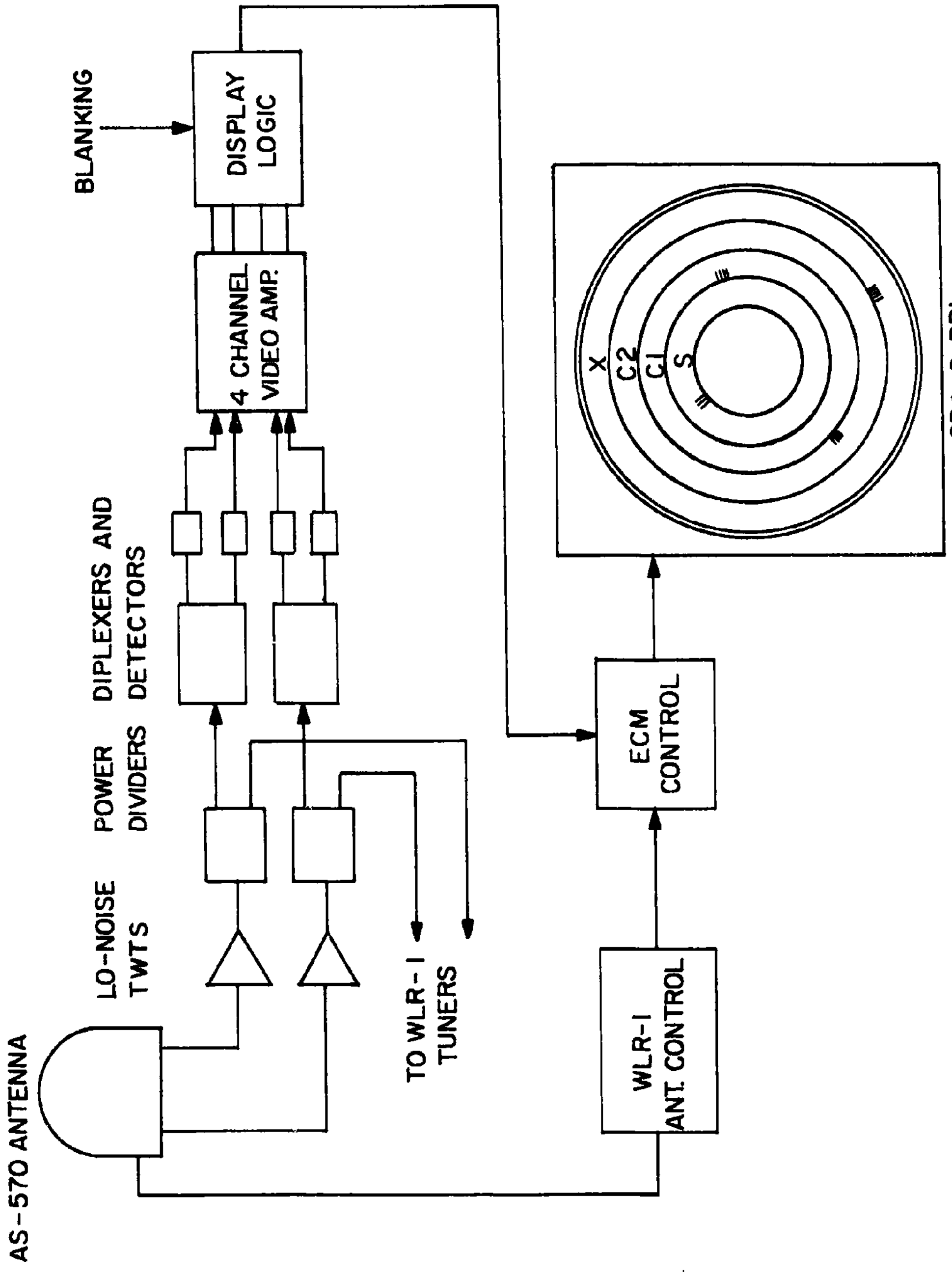

Figure 5 - AS-570 Intercept Receiver

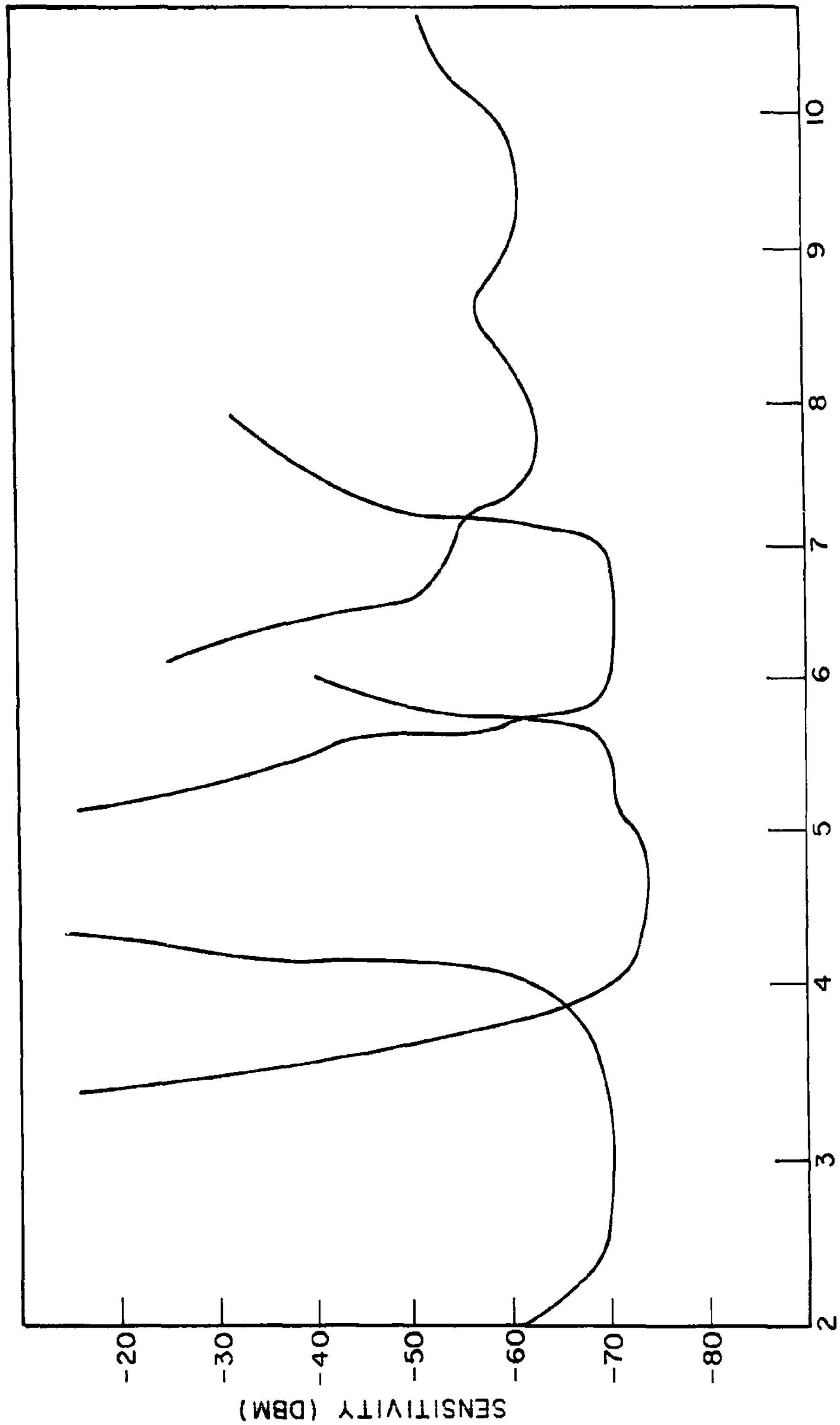

Figure 6 - Sensitivity of AS-570 Intercept Receiver

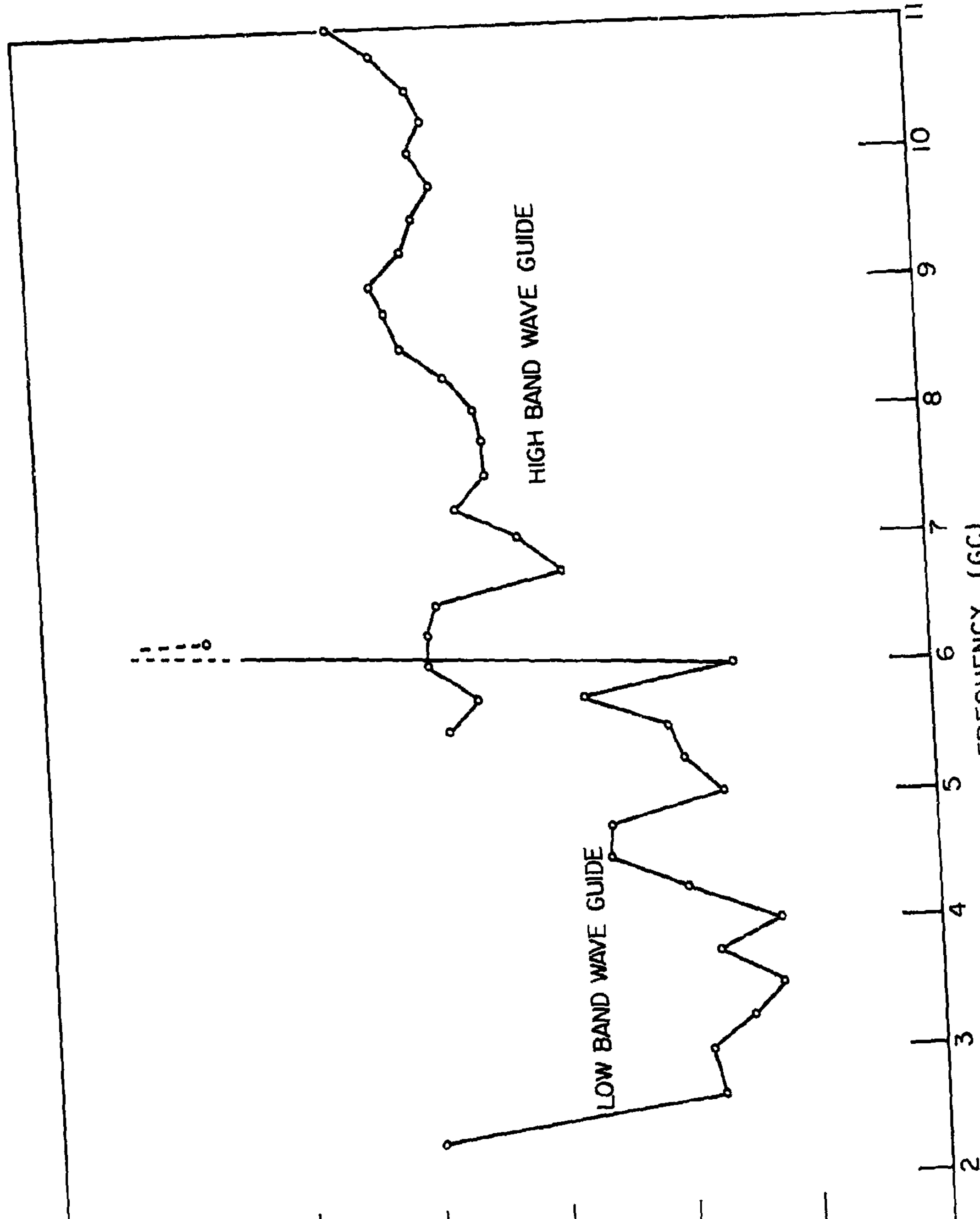

Figure 7 - AS-570 Intercept Receiver Waveguide Insertion Loss

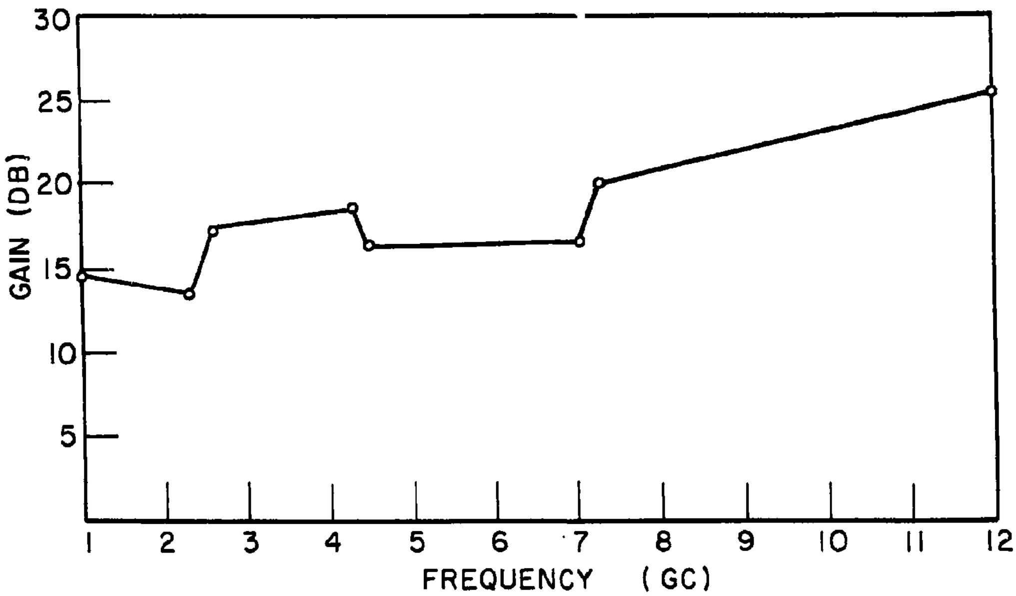

Figure 8 - Gain of AS-899/SLR Antenna

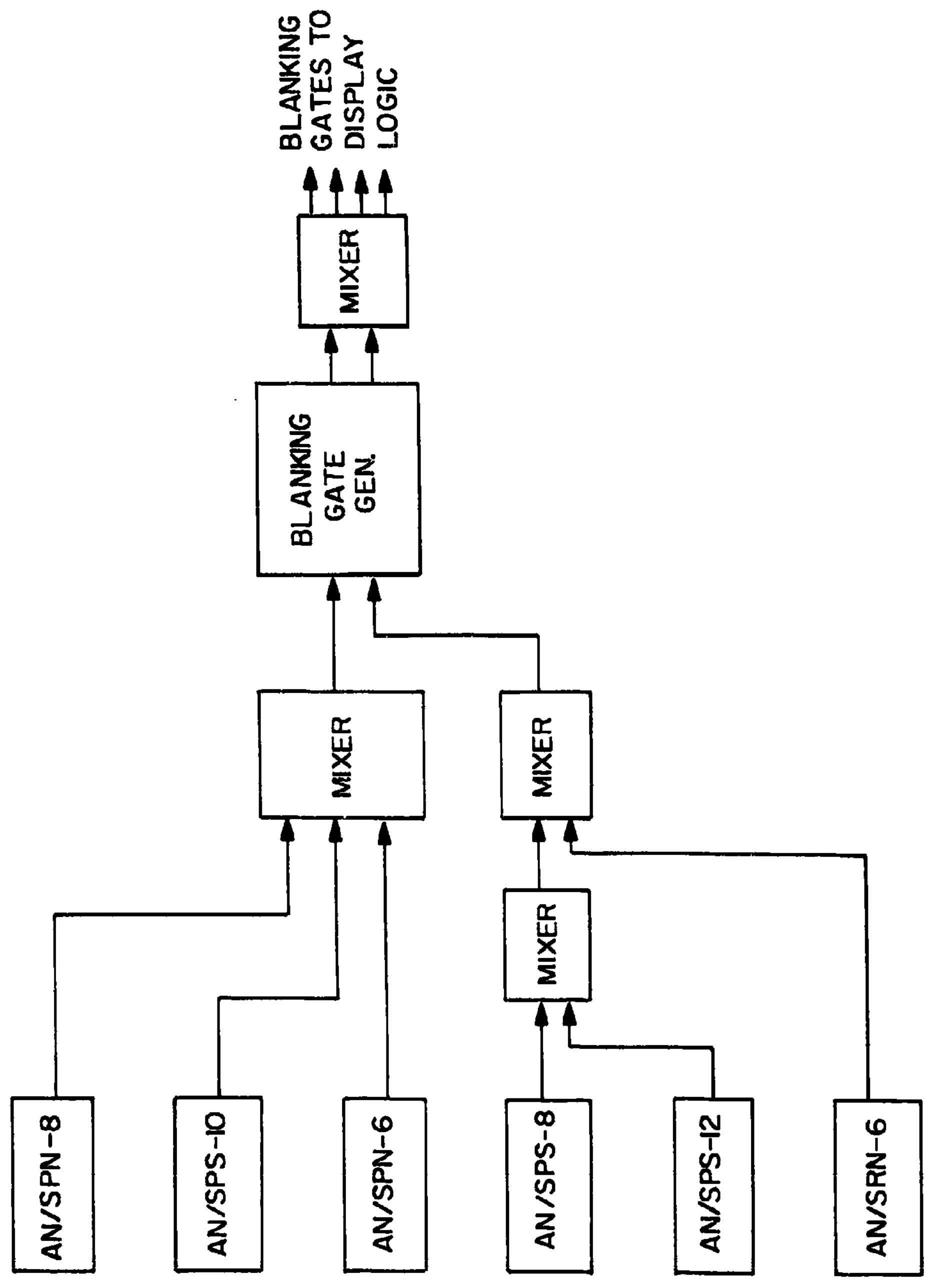

Figure 9 - Blanking System AS-570 Intercept Receiver

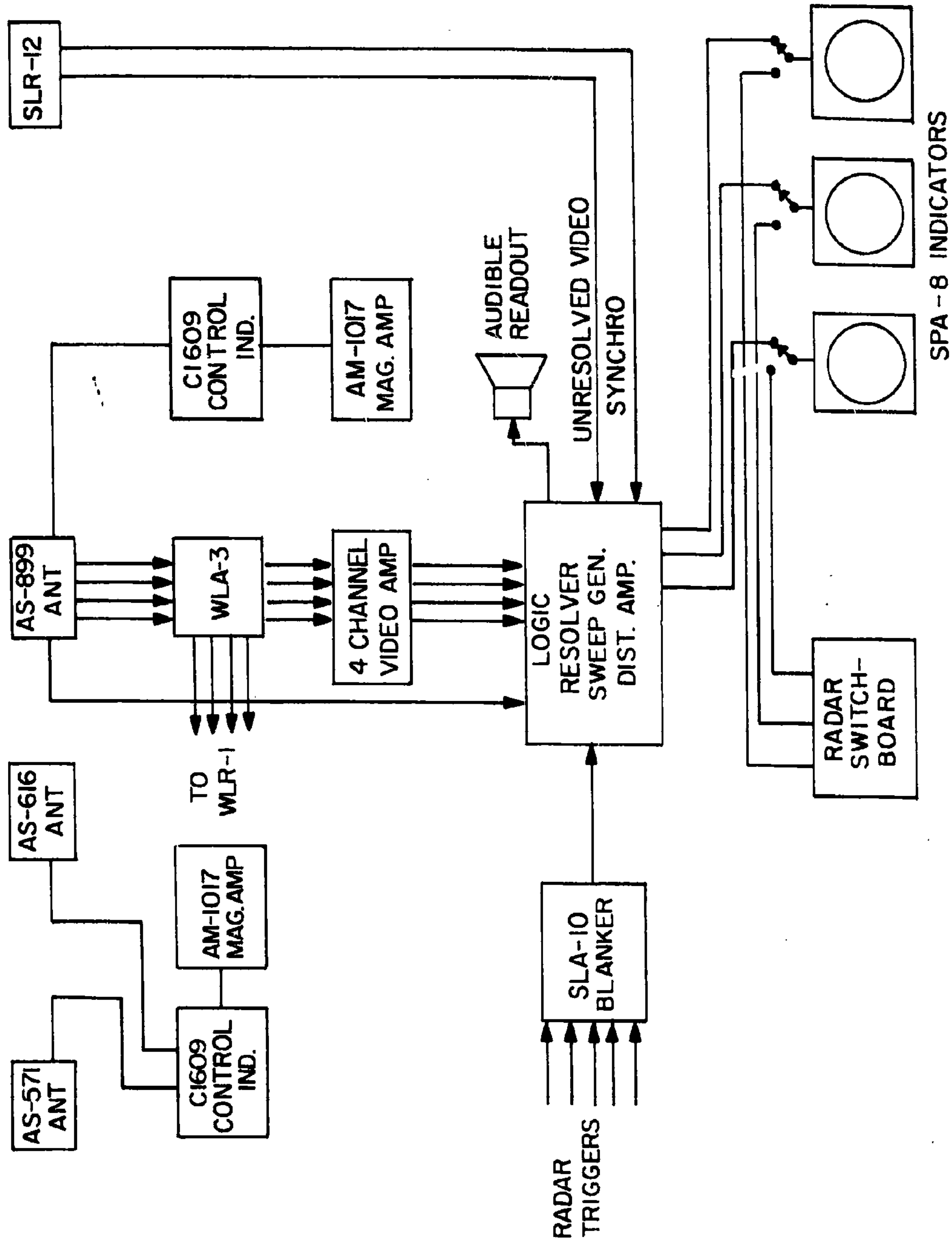

Figure 10 - Processed Video Intercept Receiver

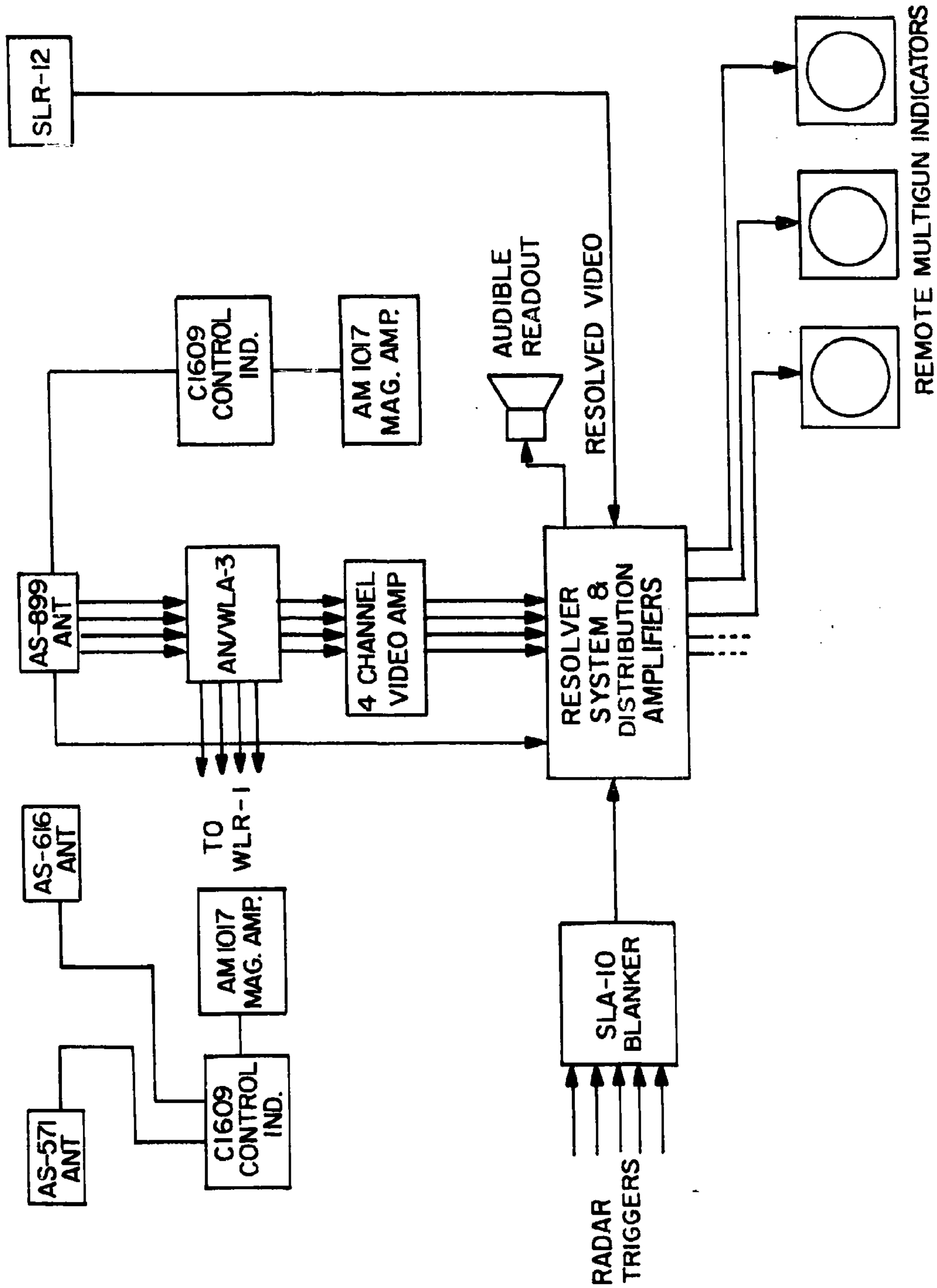

Figure 11 - Analog Video Intercept Receiver

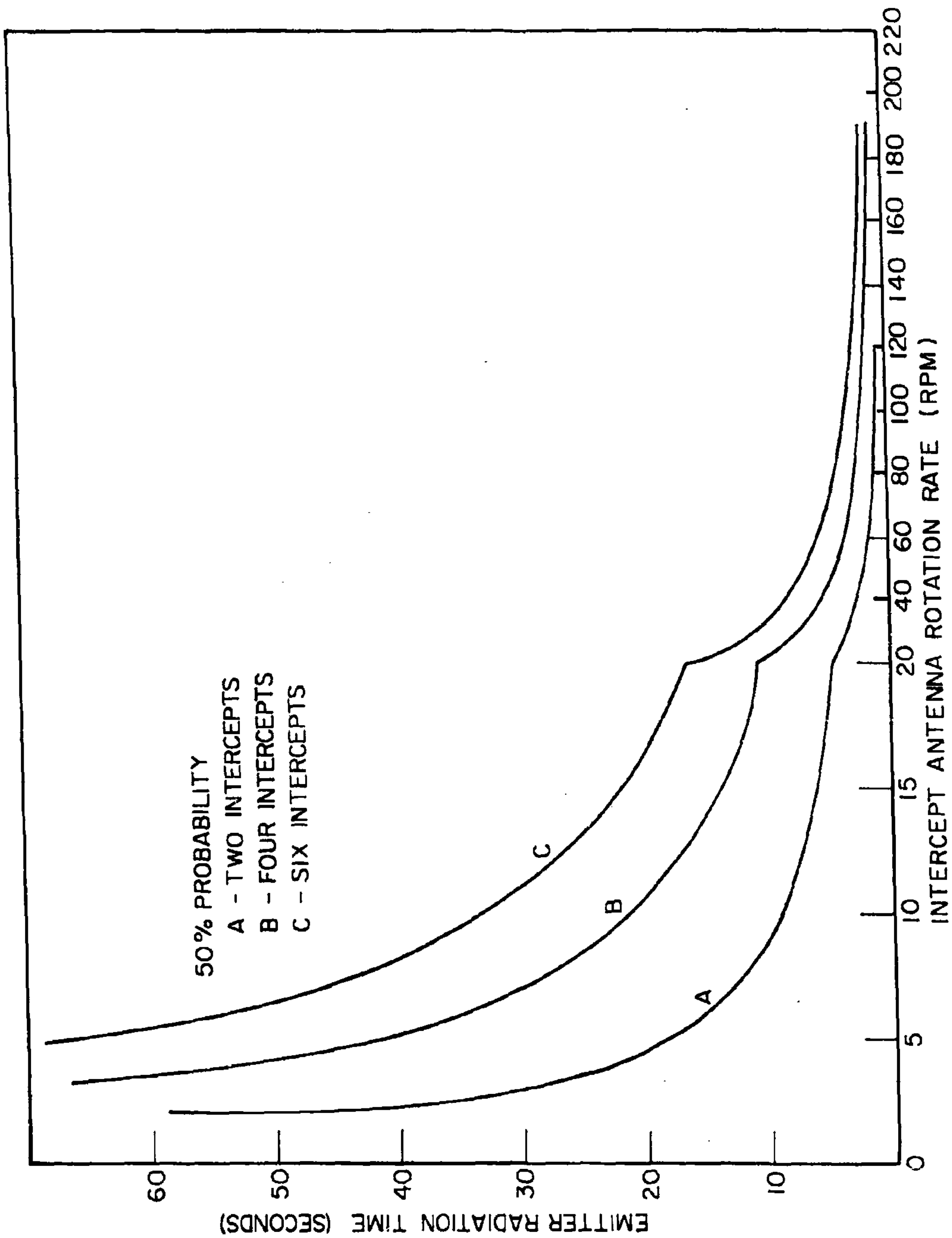

Figure 12 - Effect of Antenna Rotation Speed on Intercept Time

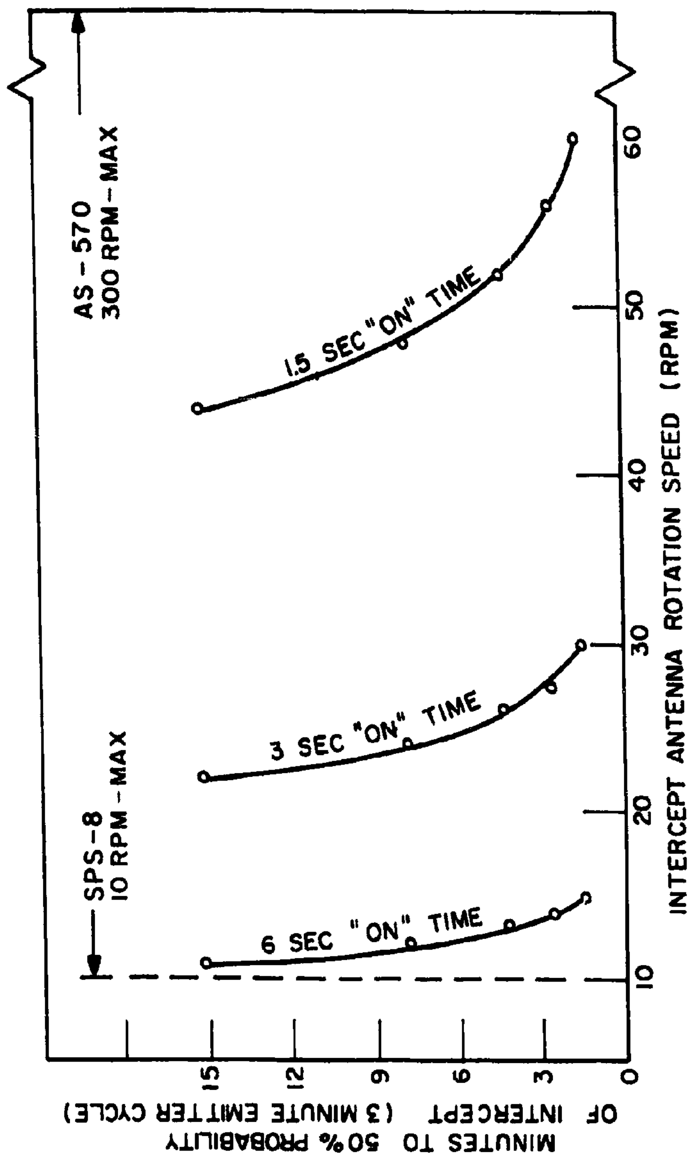

Figure 13 - Average Time to Intercept for "Winking" Emitter

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